Making results of complex systems-based landscape models more accessible to non-expert users

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Abstract: Current approaches to landscape management have seen an increasing use of complex models based on an integrated systems approach to describe landscape dynamics. The availability and use of such models provides greater flexibility for informing policy decisions than do single issue approaches. However, model complexity precludes their direct use by all but the most technically savvy.

The issue of modellers providing access to results of complex models to non-experts in a flexible way was addressed in this study. The government of Victoria (Australia) needed to be able to assess potential impacts of different land use changes on a variety of factors related to water availability and quality in two priority catchments. The Forest Policy branch of the Department of Primary Industries Victoria (DPI-Vic) who commissioned this work wanted flexibility in the presentation of results of a complex spatial model with particular emphasis on making them intuitive and interactive for end users.

To respond to these needs, a GIS-like Spatial Viewer was developed to allow non-experts to query model-based estimates of impacts of land-use change. The land-use changes of interest were the conversion of pasture or cropland to forest and vice versa. The catchment characteristics of interest were recharge, evapotranspiration, total flow to stream, above-ground vegetative carbon, water quality (in-stream nutrients), soil erosion (that also impacts water quality), depth to water table, and in-stream salt.

Underlying the Spatial Viewer is a series of spatial layers/outputs from a sophisticated hydrological model – CAT (Catchment Analysis Tools) – that describes interacting landscape processes. CAT was calibrated for both areas using long-term climate records, on-ground measurements of surface and sub-surface water, and local expert knowledge of the hydrological system. The raw spatial layers are composed of 1ha cells/pixels that indicate the amount of above-ground vegetative carbon, for example, that would be present if the entire cell were covered by pasture, crop, or forest.

The Spatial Viewer combines this information with a map of current land use to assess the actual or potential impact(s) of changing the land use within spatial units of interest. The user can obtain this information for individual 100 ha cells – i.e. $1km^2$, a spatially contiguous selection of 100 ha cells, individual Sustainable Diversion Limit (SDL) units, or multiple SDLs. Results of Spatial Viewer queries are presented as maps or tables.

The Spatial Viewer supports decision-makers by providing estimates of the impacts of land-use change for key catchment parameters at multiple spatial scales. For macro-scale landscape planning, it produces catchment maps showing areas that are highly sensitive to land-use change. A more localised assessment can show the impacts of changes in smaller specific areas. Results of such queries can be linked to ancillary information to, for example, evaluate regional economic impacts, project landscape health under multiple change scenarios, and facilitate community consultation.

Keywords: Spatial data, land-use conversion, hydrological models, landscape models, decision-making.

1. INTRODUCTION

There is an increasing trend for science results to be one of the inputs into the development and implementation of public policy. Coupled with this trend in landscape management is the development of increasingly complex holistic models that address inter-connections among multiple natural processes. Such models provide more flexibility for exploring alternative policy options than do single-factor or single-scenario studies. However, such models generally require a high level of scientific and technical expertise to produce desired outputs and interpret them in a meaningful way.

Conceptually, there are two ways to make models and their outputs available to non-expert users.

First, one can develop a user interface that hides model complexity and permits users to directly pose model queries in semi-natural language and to examine various what-if? scenarios. Though this seems to be a highly desirable approach, the time required to produce such an interface is prohibitive, particularly considering that computer code of many models is not readily adaptable to such interfaces. And whereas it might seem that such an interface could be produced with an appropriate business model and development plan, many models of interest are "public good" and are probably not commercially viable.

The second approach is to "pre-package" model results with a custom-designed interface. Rather than having to run models themselves, in this approach model users are supported by an interface that supports their specific interests by summarizing results of "pre-run" model scenarios. This allows modelling experts to limit themselves to their strength -- running models to produce technically correct outputs – rather than attempting to produce robust computer interfaces for their models. It similarly allows non-technical users to query model results in flexible ways to obtain scientific advice for a variety of questions that are modeller posed in ways that are meaningful in the public policy debate. The down side, of course, is that model users do not have direct model access.

In this article, we address this second approach using experience gained in water management in the state of Victoria (Australia). We first describe the information flow that is required among modellers, interface designers, and end-users. We then present a working example of such an interface.

2. INFORMATION FLOW FOR SYSTEM DESIGN

Key to a successful outcome is a user interface that meets the needs and addresses the questions of individuals whose expertise is not technical – i.e. "non-experts" and balances those with model capability and technical limits associated with computer hardware and software. This requires a three-way approach to interface development (Figure 1).

Non-expert end-users must be able to clearly articulate what they want in terms of model outputs and interface and accept advice on the technical feasibility, complexity, and cost of what is desired. Technically oriented modellers must understand the non-technical needs of the end-users and provide an accurate assessment of the ability of their model(s) to meet those needs. Modellers must
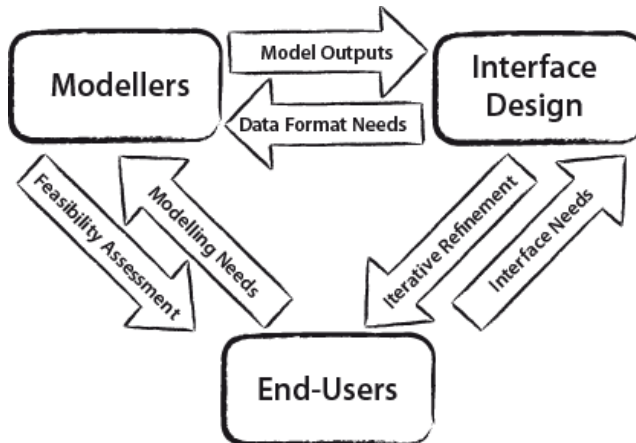

Figure 1. Schematic interactions for model access by non-experts.

also communicate with interface designers to explain model outputs in ways that allow the interface designer(s) to manipulate the model data in a way that maintains the scientific integrity of the outputs. Interface designers must also be able to clearly articulate their data format needs and modellers must work with the interface designers to reconcile model output formats with those of the interface developer.

Critical to making this work is flexibility among all concerned. Modellers must recognize and acknowledge that their model outputs and data formats are not necessarily ideal for interface designers and end-users. End-users must accept model and interface limits. And interface designers must accept that interface design is an iterative process with end-users with the latter not necessarily being able to specify all interface requirements at the beginning of the process.

The biggest challenge, however, is finding a common language for communication among all three. Simplistically put, landscape modellers are natural systems scientists who use "ecophysiographic" language, interface developers are computer scientists who use "algorithmic" language, and end-users are guardians of public interest who use "societal" language. The use of different terms for similar concepts, or similar terms for different concepts adds considerable complexity to the system design process. This is even more pronounced than might first be thought given that the use of different language among the three is indicative of more deeply embedded differences in the way of thinking and working through problems.

3.   POLICY AND MODELLING CONTEXT

In June 2004, the Victorian (Australia) government released its White Paper on Water (Government of Victoria 2004). One of the points discussed was "Addressing impacts of Catchment Land Use." This in turn mandated an assessment of high, medium, and low impact zones for new forest plantations under what was termed "Action 2.20."

To achieve the goals of Action 2.20, the Catchment Analysis Tool (CAT) was employed (Weeks *et al.* 2008). CAT is a landscape model based on components that algorithmically and mathematically describe various landscape processes – e.g. soil erosion, agricultural and forest biomass development. Underpinning the CAT are hydrological models and conceptualizations that permit the linkage of ecophysiographic, climate, and paddock-scale land use data to evaluate the impact of different types of vegetation, farming systems, and land management options on a variety of landscape parameters. The impact(s) can be determined at a single point in time or over a specified time period. Similarly, outputs of the CAT are spatial thereby permitting impacts to be determined locally and across regions of desired sizes.

Given resource constraints, CAT modelling was undertaken on two areas rather than the entire state of Victoria. For illustration purposes we focus only on the area to the west of Melbourne associated with the Corangamite Catchment Management Authority (CMA; Figure 2). Corangamite is one of 10 CMAs in Victoria, it has a population of around 350,000 and a total area of 13,340 square kilometres. Key environmental outcomes that the Corangamite CMA is addressing include salinity management and reduction, carbon trading, managing environmental flows and better soil health. Hydrological processes have an impact on all of these environmental issues, and outputs from the CAT model can provide valuable information for policy and decision-makers in working toward better environmental outcomes at a regional scale.
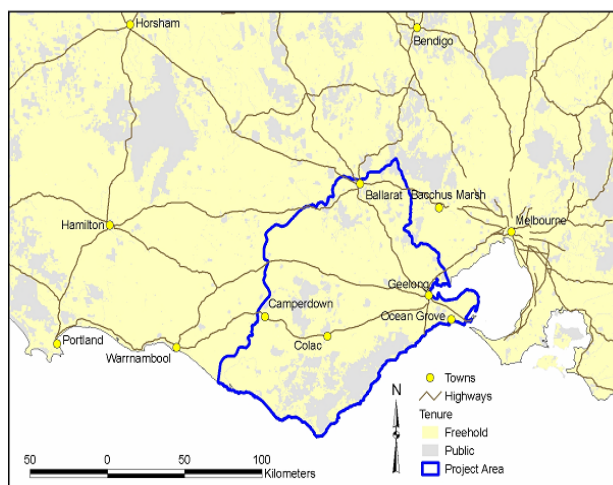

Figure 2. Corangamite Catchment Management Authority used for illustrative purposes.

Of interest for Action 2.20 was the loss or gain of pasture, crop or forest and the local and regional impact of land conversion on eight landscape parameters: aquifer recharge, evapotranspiration, total flow to stream, (above-ground vegetative) carbon, water quality (soil erosion and in-stream nutrients), depth to water table, and in-stream salt. Achieving the goals of this study required that four geographically co-registered surfaces for each landscape parameter be produced. One surface was the amount of erosion (for example) associated with the current land use. The remaining three surfaces were the estimated erosion that would occur if the entire area were covered in pasture, crop, or forest. This resulted in a total of 32 base surfaces being required for each area – four land uses by eight landscape parameters. These surfaces were produced as cell/pixel-based files with 100 m resolution – i.e. each cell represented 1ha or $10000m^2$. From these, current levels of parameters of interest could be determined as could impacts of land use change via subtraction of layers.

4.   THE SPATIAL VIEWER AND POLICY NEEDS

The Spatial Viewer was designed to facilitate querying of the model layers and to produce the impact layers without the need for cumbersome algorithmic and mathematical manipulation of layers. Given the quantity of data, to create the Spatial Viewer it was first necessary to specify the required spatial resolution of outputs; this required the 1ha cells to be aggregated. End-users specified that 1km (100ha cells) resolution would be

sufficient for most purposes, but that it would also be useful to be able to readily obtain information for hydrological sub-catchment known as Sustainable Diversion Limit units or "SDLs". These are spatial units for irrigation management for which sustainable diversion limits of water have been determined. Managing water resources sometimes requires knowledge of how much water has been allocated in an area relative to likely impacts of land-use change; embedding query capacity for SDLs in the Spatial Viewer provided this.

Another issue that had to be addressed was how impacts would be reported. At times, end-users want to ask questions such as "Where are the areas that could be converted to forest, and what would be the impact of aforestation on those areas?" Implicit in this question is a need to know what the current land use is – i.e. one does not change land use by planting trees on an area that is already covered by trees. But end-users also want to be able to ask questions that simply address landscape response regardless of current land use – e.g. "Which areas are most sensitive to deforestation?"

To address this, it was decided that the Spatial Viewer would address both. "Actual Impact" addresses questions involving current land-use whereas "Potential Impact" addresses landscape sensitivity. For both of these, an end-user must specify a land use change of interest – e.g. pasture → forest. Actual Impact for a 100ha cell or SDL is then estimated by determining how much of the cell/SDL is covered by pasture and converting the entire amount to forest. Associated surfaces are then summarized based on the percentage of each cell/SDL covered by pasture. Note that if a given cell/SDL has no pasture, then the Actual Impact of this land use change would be zero (0) for all landscape parameters. Potential Impact instead assumes that for a pasture → forest land use change an entire cell/SDL is covered by pasture (regardless of the actual land use), and that this is entirely replaced by forest.

To facilitate such queries, the 32 surfaces original surfaces were condensed into two spatial databases – one for 100ha cells and one for SDLs. This required extensive database manipulation that first required overlaying of the original layers to produce a single geographic layer composed of 1ha cells each of which had 32 associated attributes. These were then re-sampled and summarized based on vector format layers of 100ha cells and SDLs. Undertaking these complex operations produced a database that had all necessary information in an efficient format to permit real-time responses to queries.

The Spatial Viewer has been developed as a stand alone GIS application using the ESRI MapObjects technology (Figure 3). The Spatial Viewer contains standard GIS functionality e.g., pan, zoom, and data import/export, select area of interest etc. -- and also contains query functions specific to Action 2.20 needs. One of these functions is the relatively simple cartographic display of information and associated statistics of the surfaces in the Spatial Viewer scaled based on the frequency distribution of all cell values (Figure 4). The Spatial Viewer also permits the selection of individual cells or SDLs and the display of Actual Impact and Potential Impact of a given land use change (Figure 5).
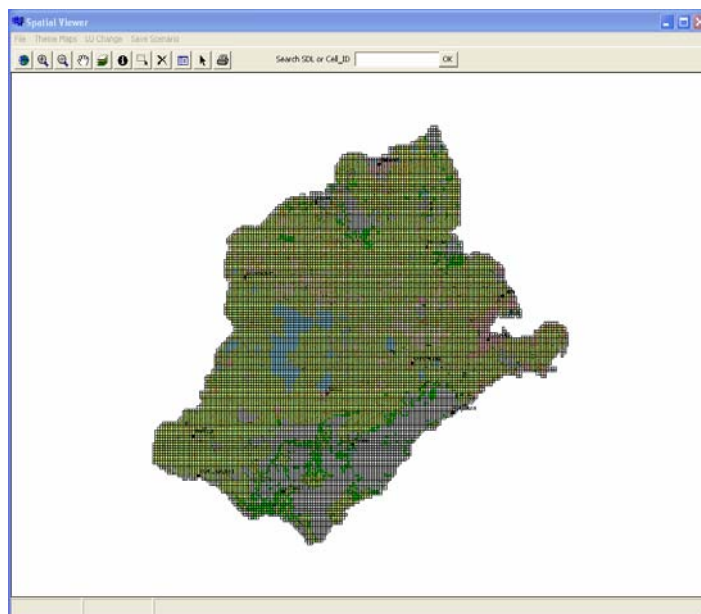
Spatial Viewer databases have been developed using the ESRI, Shapefile format. Hence should alternative analysis or high quality cartographic

Figure 3. Spatial Viewer Interface.

output be required, users can undertake what is desired using both commercial and open source GIS software packages that can read Shapefile data files. The Spatial Viewer satisfies its mandate through intentionally simplified functionality by providing a cut-down, user friendly 2D GIS user interface with query capability.
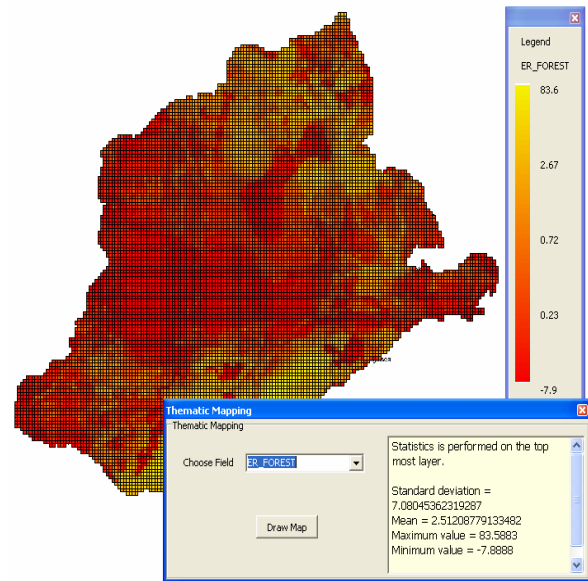
Figure 4. Example of display of unsummarised layers in the Spatial Viewer and associated statistics. (This example is the amount of erosion in tonnes/ha that would occur if the entire area were covered by forest. Scale reflects frequency distribution of all cells.)
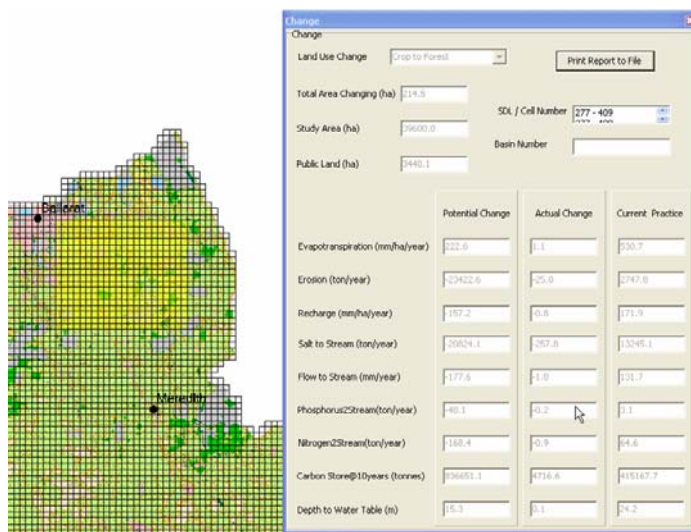

Figure 5. Display of Actual Impact and Potential Impact of a selected land use change (crop → forest in this case).

5. DISCUSSION

5.1 Policy Issues

One of the biggest challenges in work such as this is for experts from (three) different domains to understand the challenges in each domain. If policy is the end-user as was the case herein, it is particularly critical for policy personnel to not only be able to clarify what is desired, but to also understand and accept model, technological, and budget limitations.   This was facilitated in this project using an interactive project management process throughout. A series of organisational meetings were held throughout the life of the project that included key personnel from the three groups – policy, modelling, and geospatial technology. Initial meetings clarified the scope of the project and the nature of the end-product. Subsequent meetings

allowed for modifications to be requested and their modelling and technological feasibility, impact on resources, and importance to be evaluated. In addition, during the project the project leader met repeatedly with members of all three groups to ensure that global needs, project resources, and progress was understood by all. Though such activities are a part of virtually all projects, they are even more critical in a project such as this because three disparate groups with different vocabularies, backgrounds, and capabilities were working towards a single outcome.

5.2 Modelling Issues

In producing mechanisms such as the Spatial Viewer that are focused on increasing access to and use of sophisticated models, some modelling detail is necessarily lost through rasterisation and aggregation processes. One example in this work involved the specification of the impacts of aforestation. In doing so, the time at which impacts are considered is quite important. Take the landscape parameter (annual) evapotranspiration. One of the political issues surrounding the establishment of forests in Victoria is the increase in water consumption compared to crop or pasture land use due to the potential for a consequent decrease in recharge and streamflow. When forests are initially planted, any increase in water consumption is likely to be minimal. However, as the tree crowns of the forest close, water consumption will be maintained at a much higher level until harvest. Similar issues are evident for the impact of tree establishment on all other landscape parameters considered. However, whereas assessing impacts using a relatively young tree age will indicate a positive impact from tree planting, the use of a young age will indicate a negative impact for others and vice versa. Thus the year that one selects for determining impact can be quite important.

This factor is indicative of a potential danger associated with producing something that simplifies access to modelling results. The Spatial Viewer was developed in large measure to give *relative* indications of actual and potential impacts of land use change. However, it was not intended to be used to provide locally reliable *absolute* estimates of different landscape parameters and impacts on them of land use change. Because of the possibility of this occurring and the subsequent danger of information being misused in the public debate, two actions have been taken. First, the distribution of the Spatial Viewer is controlled. Second, a detailed report on the modelling and the Spatial Viewer has been produced (Lowell *et al.* 2008). It is provided to anyone who receives a copy of the Spatial Viewer. This report documents all of the assumptions implicit in the modelling that was undertaken and provides information about the reliability and accuracy of the model for various spatial scales and landscape parameters.

5.2 Spatial Viewer Issues

As mentioned in discussing the design and creation of the Spatial Viewer, a number of compromises had to be made by the modellers, the end-users, and/or the interface designers. One example is the colour ramp used in Figure 4. Initially, the end-users specified a desire to have a Spatial Viewer that produced maps showing three to five classes – Low to High – with no associated numbers for landscape parameters. This would have been the equivalent of showing relative but not absolute impact. However, this changed when it became apparent that there was the potential for maximum impact to be, for example, 2% for one landscape parameter but 50% for another. In both cases, class maps showing Low to High would have been produced. In the former case, however, an impact of 2% would have been labelled "High" whereas in the latter an impact of 10% would have been labelled "Low." To avoid this issue, the project team attempted to define thresholds for each of the landscape parameters that had some intrinsic or land management-based meaning for Low and High. This was untenable from both a policy and a science perspective. Hence after a considerable amount of iterative communication, the colour ramp was selected as a solution.
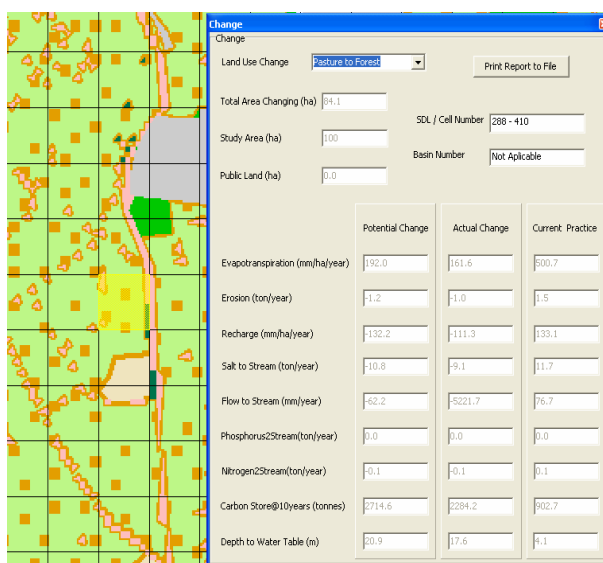

Figure 6. Example illustrating issue associated with Depth to Water and the selection of a relatively small land use change.

Fully documenting the Spatial Viewer and associated modelling, and having extensive

dialogue among collaborative parties did not resolve all issues. In particular, the landscape parameter Depth to Water Table presents an interesting problem. The example in Figure 6 suggests that if the 84.1ha of pasture on the square selected (in yellow) were converted to forest (Actual Impact), the depth to water of the square would increase 17.6m (from 4.1 m to 21.7 m). In fact, the planting of 84.1ha of forest will not change water depth by 17.6m. The Spatial Viewer is based on the mathematical summary of surfaces produced by modelling individual parameters as if the entire Corangamite CMA area (1.37 million ha) were covered by pasture, crop or forest. Hence the correct interpretation of the example in Figure 6 is that if the entire catchment were converted from pasture to forest, the Depth to Water for that cell would change 17.6m. Note that modelling impacts of land use change by changing a single cell at a time was possible (and indeed has been done using the CAT depending on the goal of the modelling). However, impacts would have been so small that the results would have been negligible. The solution is to ensure that users are well-informed of this issue, its cause, and to interpret Depth to Water results in a relative rather than absolute manner.

Incidentally, the other landscape parameters would be subject to a similar effect. However, Depth to Water is the landscape parameter most impacted by off-site land use change. For the other parameters, the impact of land use change at a given location is most dependent on the change at that location. Therefore, even though other parameters have similar issues, the impacts are negligible or at least much less pronounced.

6. CONCLUSIONS

Increasing access to, and uptake of, results of sophisticated models requires effort beyond the modelling itself. Creating a means to accomplish this requires collaboration among model producers, model consumers, and those who create software interfaces. Moreover, it requires compromise and a common language among those who are most aware of the science underpinning a model, those most concerned with the use of science to support societal goals, and technically and algorithmically oriented individuals responsible for the development of software interfaces. Because of the potential for misunderstanding among these individuals and other eventual end-users, written documentation on model conception and usage must be produced. Even if this occurs, however, some of the subtleties of the modelling and how they relate to the process(es) being modelled is lost through necessary simplification. Despite this, putting forth the effort to create end-user targeted model delivery mechanisms will enhance the utility of model outputs to influence real-world decisions. Experience from this project also suggests that multi-perspective projects such as this provide the unintended benefit of allowing modellers to better understand policy-makers' needs, and for the latter to better understand modelling requirements and limitations. It is envisaged that tools such as the Spatial Viewer will be increasingly developed and used to facilitate the dissemination and longevity of complex land use model outputs. Future research is required to formerly evaluate the benefits in providing non-expert modellers with intuitive and interactive interfaces such as the Spatial Viewer for interrogating land use models.

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